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Update of the Maintenance Task Database for Heating, Ventilating, and Air-Conditioning Systems

by
David M. Underwood

The Maintenance Resource Prediction Model (MRPM) is a computer system designed to assist in planning and programming maintenance resources, based on the anticipated resource requirements of actual installation facilities, for prediction periods of 1 to 10 yr.

This report corrects areas of deficiency in the existing MRPM Database where existing information did not reflect current heating, ventilating, and air-conditioning (HVAC) system technology. These areas include chlorofluorocarbon (CFC) change out, gas engine driven cooling, direct-fired absorption cooling, desiccant cooling, evaporative cooling, and heat pumps. The report describes the technologies involved and the items that affect the maintenance requirements, and lists the specific sources of information used to create the spreadsheets that are included as an appendix. The original HVAC portion of the MRPM task database was introduced in USACERL Special Report P-91/21 of May 1991.

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Foreword

This study was conducted for U.S. Army Corps of Engineers, Huntsville Division, Engineering and Support Center (CEHNDED/ES-A) under reimbursable project RD/M-HND, "Update of the Maintenance Database for HVAC Systems." The technical monitor was Terry Patton, CEHNDED/ES-A.

The work was performed by the Engineering Division (FL-E) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was David M. Underwood. Larry M. Windingland is Acting Chief, CECER-FL-E, and Donald F. Fournier is Acting Operations Chief, CECER-FL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

COL James T. Scott is Commander of USACERL, and Dr. Michael J. O'Connor is Director.

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Background

Building maintenance cost estimates are needed during planning, design, and operation of Army facilities. Along with construction and operating costs, maintenance costs are an important component in overall life-cycle cost. Maintenance costs are currently estimated from the Maintenance Resource Prediction Model (MRPM) Database. Since the development of that database, several technologies have come to be used more frequently and thus their maintenance requirements are of concern. It is the purpose of this report to document the efforts to organize these costs.

Objective

The objective of this research was to correct deficiencies in the existing HVAC maintenance databases where existing information does not reflect current HVAC technology.

Approach

Three avenues for collecting the desired data were pursued. First, a literature search was performed to determine what data had already been documented. As expected, no database containing maintenance and repair data was found on even one of the technologies. Instead, general information was found in bits and pieces in articles and books. The second data collection method was to contact manufacturers and distributors. Requests were made for operation and maintenance manuals that contained recommended maintenance tasks. Contacts consisted of requests by telephone, facsimile, and correspondence. In addition to manufacturers and distributors, industry groups such as the Gas Research Institute, the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), and the California Institute for Energy Conservation were also contacted. Finally, experts in the field were also contacted to determine what maintenance practices they regularly followed. The data added to the database are included as an appendix to this report in the form of spreadsheets. These data represent a combination of the information obtained from the Information Sources listed at the end of each chapter. Where data were not available on specific sizes of equipment, the available data were extrapolated. Some data, such as some of the hours of labor required to perform preventative maintenance, were not available from several sources. In those cases, an engineering judgement was made based on the available data and engineering experience.

Mode of Technology Transfer

The information gained from this project will be disseminated through the MRPM Database, which now exists in a Microsoft® Windows™ version.

2 CFC Refrigerant Change Out

Background

Because of the ozone depletion potential of the refrigerants used in vapor compression cooling systems, the use of these refrigerants is being phased out. The schedule of this phase out, as adopted by the Montreal Protocol of 1987, varies according to the type of refrigerant, based on its ozone depletion potential. The amount of chlorofluorocarbon (CFC) production decreased each year, with no production allowed beginning 1 January 1995. For HCFC-22 (also referred to as R-22), which is the most widely used refrigerant, production and consumption will be frozen at a baseline level. However, because of its relatively low ozone depletion potential, this freeze is not scheduled to occur until 1 January 2010. This delay in phase-out significantly affects the approach to be used in dealing with existing inventories of CFC refrigerants and the equipment that uses it. Additionally, a ban exists on the production and consumption of the virgin chemical unless it is used as feed stock or refrigerant in appliances manufactured before 1 January 2020.

The costs associated with converting to non-CFC refrigerants vary quite extensively from the type of chiller, refrigerant used, and capacity degeneration sensitivity.

Three options that should be used in dealing with the current inventory of CFC-based equipment [1] are:

- **RETROFIT** Replace CFC with non-CFC refrigerant and perform necessary retrofits.
- **REPLACE** Replace entire units with non-CFC units.
- **ATTRITION** Run unit "as-is" until its useful life is over, making sure the leak rate is within the applicable regulatory annual leak rate allowed.

The first option is the concern here. Replacement of an entire unit will vary with the application, and the cost will likely change greatly with time. Maintenance of these non-CFC units is the same as that of the current CFC units.

The current stock of chillers and the refrigerant used is not known exactly, but estimates have been made [6]. The estimated usage of refrigerant in the U.S. Army is 44.9 percent R-22, 24.1 percent R-12, 18.4 percent R-11, and smaller percentages of R-502, R-500, and R-113.

When many of these replacement refrigerants are used, such as R-123, an air monitor should be installed. Monitoring is important because of the toxic nature of this replacement refrigerant, which is expensive. The cost of the monitors range from $1,500 to $5,000 [2]. This information was not included in the database update.

Database Addition

Component:	Chiller xxxx Tons
System:	Cooling Generation
Subsystem:	Equipment
Task:	CFC Change Out
Subtasks:	Removal/Disposal of old refrigerant
	Modification of Chiller Equipment
	Charging with new refrigerant

The current database includes the following chillers:

A/C DX Packaged: 5, 20, and 50 Ton
A/C Window 1, 2 Ton
A/C Pad Mounted: 5, 20 Ton
Air Cooled Reciprocating: 5, 10, 15, 20, 50, 100 Ton
Water Cooled Reciprocating: 10, 20,50, 100, 200 Ton
Hermetic Centrifugal: 100, 300, 900 Ton
Hermetic Double Bun: 100, 300, 900 Ton
Open Centrifugal: 300, 900 Ton

None of these chillers, however, require a proactive replace/retrofit approach. A U.S. Navy report [3] recommends that units of 5 tons and smaller be dealt with through attrition of the units. In other words, there is no need to be concerned about equipment that uses CFC on a small scale. Equipment under 100 tons uses nearly exclusively R-22 (an HCFC), which has a very low Ozone Depletion Potential (ODP) compared with other refrigerants. The standard for ODP is R-11, which has an ODP of 1. R-22 has an ODP of 0.05, meaning that it has only 5 percent of the destructive effect on ozone as compared to R-11. The current industry practice is to deal with

R-22 equipment through attrition also. For this reason, the cost of CFC change out was included in the spreadsheet only for those units for which a proactive approach is expected.

Phaseout will occur at different rates for various users, so old refrigerants recovered during a retrofit have a value that is included in the spreadsheet. This recovered refrigerant could be used either as a supply for other machinery that is not planned to be retrofit as non-CFC or sold to utilize it in existing equipment. The value of this recoverable refrigerant is extremely difficult to determine except on a case-by-case basis. Contaminated refrigerant, for example, is worth much less than uncontaminated refrigerant. Any recovered refrigerant with greater than ½ percent of another refrigerant is considered to be contaminated. Removal of the contaminated refrigerant will result in a cost to the customer. Contamination occurs more often in high pressure chillers than in low pressure chillers. While no statistically significant data are available on the frequency of refrigerant contamination, sources indicated that it is a fairly isolated problem and that, for the most part, refrigerants can be assumed to be uncontaminated. Sources indicated that uncontaminated R-22 has a value of approximately $1.50/lb and that most others have a value of approximately $3.20/lb. If the refrigerant is not needed for other chillers, the rebate paid for the reclaimed refrigerant could be used to offset the cost of non-CFC conversion. Other sources indicated that, because of the unknown state of the refrigerant, they would not pay for the reclaimed refrigerant and, in fact, in some cases would charge for its removal. Additionally, the value of all refrigerants is very unstable, making any estimation of value/debt difficult. For purposes of the database, it was felt that an average value of zero was both conservative and the best reflection of present value. Categorization according to the refrigerant type is fairly easy. Those chillers equal to or greater than 100 tons generally use CFC11, while those less than 100 tons usually use CFC22. Chillers using other refrigerants account for only 13 percent of Army chillers. While not exact, chillers typically have approximately 2 lb of refrigerant for each ton of capacity [6].

R-11-based chillers are currently the most challenging to convert to non-CFC refrigerant use and are, therefore, the most expensive. While most other chillers can be converted without significant mechanical modifications, R-11-based chillers require significant retrofit. Depending on the individual requirements, modifications such as impeller changes, gear synchronization, seal and gasket replacement, and motor modification are required. The ozone-friendly replacement for R-11 is R-123.

R-12- and R-500-based chillers (high pressure/low temperature) will likely be replaced with R-134a. According to a Navy report [1], "a direct retrofit from CFC-12 or CFC-500 to HFC-134a that includes the new refrigerant and service time to flush the system of its mineral oil and recharge with the recommended synthetic oil will cost approximately 26 percent of a new chiller price. The retrofit from CFC-12 will result in an 8 to 10 percent capacity loss with a 1 to 2 percent loss in efficiency. Retrofits of CFC-500 chillers result in little or no capacity loss and about 0.5 percent efficiency loss. As with the low pressure systems, a more extensive retrofit can regain the capacity and efficiency of the original configuration. This would require changes in impeller and/or speed. Overall retrofit costs generally range from $20K to $70K per system." Another report [2] from EPRI suggests that medium temperature refrigerant units, such as those commonly used in commissaries, could be retrofit with R-22. Since then, however, new refrigerants have been developed, and the phase out of R-22 production has been accelerated. Therefore, that approach is not likely to be taken at this time.

Information Sources

[1] Navy CFC Clearinghouse (703) 769-1883; 769-1885 Fax Internet NavyOzone@aol.com.

[2] Sorensen Thomas C., "Refrigerant Leak Detection in Mechanical Rooms," *ASHRAE Journal*, August 1996.

[3] Bell, Mestey, and Gott, "Shore Facilities Ozone Depleting Substances Conversion Guide for Heating, Ventilation, Air Conditioning/Refrigeration and Fire Protection Systems," April 1996.

[4] CFC Reclamation & Recycling Service, Inc., Abilene, TX. Dan Cooper CFC@ichange.com (915) 675-5311.

[5] "Medium-Temperature Supermarket Refrigeration Conversion From CFC-12 to HCFC-22 (R-12 to R-22)," EPRI TR-101265, December 1992.

[6] Sohn, Homan, and Sliwinski, *Chlorofluorocarbon Uses in Army Facility Air-Conditioning and Refrigeration*, USACERL Technical Report FE-93/14/ADA263634, December 1992.

[7] Beasley, Buddy, Piedmont Engineering Corporation, P.O. Box 410947, Charlotte, NC 20241-0807.

[8] Retrofit Training Guide, ELF ATOCHEM North America, Inc.

3 Gas Engine Driven Cooling

Background

Gas engine driven cooling systems use engines that consume natural gas as a fuel instead of using an electric motor to drive the mechanical cooling (vapor compression). Electric motors are considered maintenance free when compared to other forms of driving the compressor, so maintenance costs of gas engine driven chillers are expressed as a premium to that of electric driven chillers. The maintenance on the chiller itself depends, of course, on the chiller type, usage, and other factors. Gas engines used for this purpose can be classified into two categories. The more prevalent type is the diesel engine derivative. This is an engine derived from one originally intended for uses such as emergency electricity generation, which consumed diesel fuel but has been modified to consume natural gas. The second type is a smaller automotive engine that has been modified to run on natural gas instead of gasoline. The maintenance of these engines is quite different. Unfortunately, most data found do not differentiate between the two. The diesel variety lasts much longer but also costs much more initially. Because of these factors, the automotive variety is used as a throw away. That is, the automotive engine is routinely disposed of at a point when the diesel variety of engine would be overhauled.

Maintenance requirements are typically expressed as a function of either Operating Hours (OH) or Equivalent Full Load Hours (EFLH). As implied, OH is simply the number of engine run hours, regardless of load. EFLH is an integrated value based on the accumulated engine run time and the engine load. For example, an engine that runs for 600 hours with an average load equal to 75 percent of a fully rated load would have 600 operating hours or 450 EFLH (0.75×600). The recommended method of measuring EFLH is to measure fuel consumption.

Database Addition

Component:	Chiller xxxx
System:	Cooling Generation
Subsystem:	Equipment - Gas Engine
Tasks:	PM, M/R, Replacement

Subtasks: PM - Recurring, Seasonal Shutdown/Startup, Annual
M/R - Replace Cylinder Heads, Replace Engine, Top End and Overhaul, Overhaul
Replacement - Replacement

Information Sources

[1] "Gas Engine Chillers: Don't Fear the Maintenance Factor," Contracting Business, November 1995.

[2] Tecochill product manual, Table 35.1, Tecogen, Inc., 121 Barlett Street, Marlborough, MA 01752.

[3] Caterpillar Defense and Federal Products Group.

[4] Applications Engineering Manual for Engine Driven Chillers, American Gas Cooling Center, 1515 Wilson Boulevard, Arlington, VA 22209.

[5] "Engine Driven and Absorption Chiller Systems Analysis," March 1995, Science Applications International Corporation, 1710 Goodridge Drive, McLean, Virginia 22102.

[6] Davidson, K., and H.D. Brattin, "Gas Cooling for Large Commercial Buildings," *ASHRAE Transactions*, 1986, Part 1B, pp 910-920.

4 Direct-Fired Absorption Cooling

Background

Absorption is defined by ASHRAE as "the process in which refrigerant vapor is absorbed into a concentrated (strong) solution." Absorption cooling systems have two basic thermal cycles, just as does vapor compression (VC) cooling: the power cycle and the refrigeration cycle. In absorption systems, the power cycle is a vapor generator (equivalent to a boiler that produces electricity for VC) and the refrigeration cycle is the absorber (analogous to the condenser for VC). There are single- and double-effect absorption systems, but only the double-effect system can compete with the thermal efficiency of vapor compression. For this reason, only the data for the double-effect units were updated. The double effect refers to the fact that the unit has two generators, which also requires two heat exchangers and two pumps. This effect increases thermal performance by approximately 40 percent. Direct-fired refers to the direct use of fossil fuel as a heat source as opposed to other heat sources such as steam. Absorption equipment can also be classified by the condensing method used, either air-cooled or water-cooled.

Absorption cooling systems have the advantage over vapor compression systems of not having a CFC-based refrigerant. Instead, they typically use either a water-lithium bromide solution or ammonia-water as the working fluid. Absorption chillers have the following maintenance concerns:

- Units must be kept clean and tight (no leaks)
- Periodic purging because of leaks of atmospheric air into the closed system is required
- Purge pumps must also have oil changed periodically
- Tightness of units must be checked periodically
- Internal surfaces of absorber requires periodic cleaning.

According to Sweetser [1], maintenance costs for a two-stage direct-fired chiller absorption unit runs from $17 to $27/ton-year, and ASHRAE estimates it to be $22/ton-year. Replacement costs have been well documented by SAIC [2]. All of these are included in the ABSORB.xls spreadsheet in the appendix.

Database Update

Component:	Two Stage Direct Fired Absorption Chiller xxxx Tons
System:	Cooling Generation
Subsystem:	Equipment
Tasks:	Maintenance, Replacement
Subtasks:	PM - Recurring, Seasonal Shutdown/Startup, Annual

The current database contains only two sizes of direct-fired absorption chillers, 300 and 900 tons. Data were collected to reflect the current product offerings and includes eight units from 100 to 900 tons. While specific maintenance tasks have not changed, the costs and frequencies have. Available data are documented in terms of overall requirements and are not broken into individual tasks. Therefore, the updated database contains new equipment sizes with less detail, but is now more accurate and usable. The estimated costs required listed in spreadsheet absorp.xls are for an average installation.

Information Sources

[1] Sweetser, Richard S., "The Fundamentals of Natural Gas Cooling," Fairmont Press, Inc., 1996.

[2] "Engine Driven and Absorption Chiller Systems Analysis," March 1995, Science Applications International Corporation, 1710 Goodridge Drive, McLean, Virginia 22102.

[3] ASHRAE, *HVAC Applications* handbook, 1991.

[4] Fuchs, Sheldon J., *Complete Building Equipment Maintenance Desk Book*, 2nd Edition, Prentice Hall, 1992.

[5] ASHRAE, *Refrigeration Systems and Applications* handbook, 1994.

5 Desiccant Dehumidification and Cooling

Background

Desiccant cooling can be described as the cooling of an airstream through the use of a desiccant (a substance that has an affinity for moisture). This description is somewhat misleading because when moisture is removed from air, it actually adds heat to the air, which is just the opposite of direct evaporative cooling, which adds moisture to the air, thus taking heat away from the air and adding it to the water. What this means is that a desiccant cannot actually function as a cooling system on its own but must be used in conjunction with other cooling systems (called a hybrid system) unless dehumidification is the only requirement.

Desiccants hold moisture through either absorption or adsorption and are either liquid or solid. Absorbents are usually liquid and adsorbents are usually solid. Absorbents work through the relative vapor pressures of the absorbent and water vapor, while adsorbents work because of their large internal surface area, which attracts moisture. Common liquid absorbents include lithium chloride and triethylene-glycol. Some common solid adsorbents are silica gels, zeolites, synthetic zeolites, activated aluminas, cargons, and synthetic polymers.

Five typical equipment configurations for desiccant dehumidifiers are:

- Liquid spray-tower
- Solid packed tower
- Rotating horizontal bed
- Multiple vertical bed
- Rotating honeycomb wheel.

In general, liquid-based systems require more maintenance than solid-based systems. Many liquid desiccants are corrosive and, therefore, their systems require more maintenance. Also, at low humidity levels, some desiccants can dry out rapidly, which means liquid levels must be closely monitored to avoid desiccant solidification. The rotating horizontal bed design tends to have lower first costs than other units, while the multiple vertical bed design tends to have comparatively higher initial cost and more maintenance but provides significant energy savings.

The rotating honeycomb design is the most widely used because of its many advantages such as low weight, ability to use different desiccants, and an ability to achieve both high capacities and low dewpoints. The most popular desiccant cooling system is a rotating honeycomb wheel unit with evaporative cooling combination. The application of desiccant systems within the Army is primarily in commissaries, so the units added to the database most closely reflect their requirements.

Database Update

Component:	Desiccant Chiller xxxx SCFM (Retrofit and Stand Alone)
System:	Cooling Generation
Subsystem:	Equipment
Tasks:	PM, M/R, Replacement
Subtasks:	PM - Recurring, Seasonal Shutdown/Startup, Annual

Information Sources

[1] Munter Drycool, David Parkman, (512) 474-7574.

[2] DesertCool DC026 Service/Operation Manual, Engelhard/ICC, 441 N. 5th Street, Suite 102, Philadelphia, PA 19123.

[3] "Application of Gas-Fired Desiccant Cooling Systems" Cohen, B.M., R.B. Slosberg, *ASHRAE Transactions*, 1988, Part 1, pp 525-536.

6 Evaporative Cooling

Background

Evaporative cooling in its simplest form is the exchange of sensible heat for latent heat. Put another way, evaporative cooling decreases the dry bulb temperature (sensible heat) of air by evaporating water (latent heat) into the airstream to be cooled. The variations in equipment designed to cool air using evaporative methods are so great that classifying them becomes a great challenge, which, in turn, makes estimating maintenance requirements a very challenging proposition. Table 1 summarizes the variables outlined in this chapter for direct and indirect evaporative cooling.

Direct and Indirect Evaporative Cooling

In terms of cooling buildings, two different methods of using the thermodynamic effects of evaporating water to cool an airstream are direct and indirect evaporative

Table 1. Evaporative cooling variables summary.

Variable/ Value					
Cooling Type	Direct	Indirect			
Media	Aspen Fiber	Cellulose	Synthetic Fiber	Glass Fiber	Metal
Water Distribution	Rotary Pad	Drip	Sling	Sprayed Pad	
Water Circulation	Recirculating	Once Through			
Capacity Rating	Airflow	Saturation Effect	SCFM		
Pump	Hermetic	Open			
Installation	Original	Add-On			
Packaging	Stand Alone	Packaged With Heat	Packaged With Cooling	Packaged With Heating and Cooling	

cooling. As the terms imply, the direct method evaporates water directly into the air supplied to the building space, and the indirect method evaporates water into a secondary airstream, which is usually discarded in order to indirectly cool (through a specialized heat exchanger) the primary airstream to be introduced into the building space. Indirect evaporative coolers usually consist of a horizontally oriented polystyrene plastic tube through which the primary air is cooled while water drips on the exterior of the tubes, and secondary air is circulated in a horizontal crossflow and discarded. Some water is bled off to keep mineral build-up to a tolerable level. Mineral buildup on the tube exterior is dealt with either by circulating weak acid solutions or through the use of chemical additives.

Filter Media

The evaporation of water into the airstream can occur in many ways, but with evaporative coolers, this is accomplished either through filter media usually made of aspenwood or plastic foam or through rigid media of cellulose or fiberglass. Aspenwood filters, the most common, have an approximate life of 1 year [1]. Slinger-type filters tend to be either fibrous or flat latex-coated hog bristles with galvanized wire mesh screening. Corps specifications allow aspenwood fiber, refined cellulose matrix, bonded synthetic fiber, glass fiber, and nonferrous metal evaporative media for non-rotary units. Rotary-type units allow the evaporative media to be either drums or disks made of copper, bronze, or polymer material.

Water Distribution Types

All evaporative coolers require some method for distributing or dispersing water over a large surface area in order to encourage water evaporation. The more common types are described here. "Drip" units allow water to drip from the top to the bottom of the unit and range from 300 to 36,000 scfm (standard cubic feet per minute). "Slinger" units spray water via centrifugal force from a rotating unit that varies from 3,000 to 40,000 scfm and are very common in commercial buildings such as restaurants, laundries, offices, and supermarkets. "Sprayed-pad" units have a series of pads that are sprayed with water and have air drawn through them. "Rotary-pad" units have circular pads positioned vertically that are rotated so that water is picked up on the bottom portion while air is drawn through and evaporates the water in the top half.

Water Circulation

Water circulation systems are either "once-through" (also referred to as "city water"), or "recirculating pump" types. The first system does not recirculate the water once it has circulated through the evaporative media, whereas the latter does recirculate. The "once-through" units are cheaper but consume more water and need constant drainage while the "recirculating pump" units have the opposite attributes but require periodic flushing or constant drain or bleed-off. To further confuse maintenance requirements, the type of recirculating pump used in the recirculating cooler also varies, as do its maintenance requirements. Many pumps require annual oiling, but some have permanently oiled, close-coupled motors hermetically sealed in die-cast zinc housing.

Capacity Ratings

Rating these units and their maintenance is difficult. While direct expansion cooling units are easily rated in terms of capacity (usually tons), direct evaporative units also introduce vapor, which means the industry rates the products separately in airflow delivery and saturating effectiveness, requiring a calculation of the cooling capacity. Even these ratings tend to be neither certifiable nor stable for the smaller units [1]. While more useable performance ratings methods have been proposed, none have been widely adopted or approved by an organization such as ASHRAE.

Initial Costs and Maintenance

Evaporative coolers are available as add-ons to existing external centrifugal fans (a simple pad, pan, and sprayer) or as complete packaged units that stand alone. Initial cost of slinger units is about double that of drip coolers [1], but maintenance requirements are nil, with close attention to the water level being the primary concern. Rotary-pad evaporative coolers are the most expensive initially, but are the least maintenance intensive and thus the most desirable units for military installations. Reasons for this low maintenance requirement include: (1) nearly no items to corrode (thanks to the design and use of materials such as brass for the evaporative wheel), (2) no pumps or orifices to clog, (3) permanent pads, (4) factory-installed bleed-off system, and (5) enclosed moving parts. No items require yearly replacement with the possible exception of dust filters, which depends on the local climate.

Database Addition

Component:	Evaporative Cooling
System:	Cooling Generation
Subsystem:	Equipment
Tasks:	PM, Replacement

Because of the wide variety of evaporative cooling equipment and the resulting difficulty in even classifying them, very little in the way of meaningful maintenance requirements are available. ASHRAE and the California Institute for Energy Efficiency are both engaged in activities that may classify these systems and their maintenance requirements into more meaningful data in the future. Tasks added to the database include three types of evaporative cooling: indirect precooling of outside air, direct with heating, and direct-indirect combinations with heating.

Information Sources

[1] Watt, Dr. John, *Evaporative Air Conditioning Handbook*, Chapman & Hall, 1986.

[2] Evaporative Cooling Systems, Corps of Engineers Guide Specification (CEGS)-15690.

[3] California Energy Commission, Phillip Messemer, (510) 486-5380.

[4] California State Polytechnic University, Evaporative Cooling Demonstration Facility, Pomona, CA 91768, (909) 869-4527.

7 Free Cooling

Background

Free cooling is an ambiguous subject, meaning different things to different people. No form of cooling is entirely free, of course, but many methods that leverage upon ambient conditions to provide cooling at reduced costs are available and can be generally referred to as free cooling. In terms of air handlers, for instance, the introduction of outdoor air instead of return air when it requires less cooling energy reduces the mechanical cooling requirements, and can be considered "free." Since this is simply a variation in the control action of an air handler, it does not alter maintenance requirements. The use of cooling towers during reduced outside air temperatures (outdoor wet bulb temperatures below 40 °F) is also a form of free cooling. This process usually requires the use of multi-speed pumps to maintain a near constant water temperature. If cooling towers are used at temperatures below 32 °F, anti-icing measures must be taken. Additionally, a strainer (usually self cleaning) is required to keep solids from entering the chilled water system. Another form of free cooling is the "roof pond," where a building's roof is sprayed with water that is allowed to evaporate, thus cooling the roof surface. Because of the extreme simplicity of this system, once it is installed, it is considered relatively maintenance free. Installed costs are usually referred to as a premium to the roof that would obviously be installed anyway and are approximately $0.30/sq ft.

Database Addition

Because of the wide variety of free cooling implementations, meaningful maintenance requirement additions to the database are minimal. Free cooling techniques such as rock-bed indirect cooling, the Cool Pool system, and solar systems combined with desiccant systems are technologies still too sparsely used for meaningful maintenance data to be available. However, because cooling towers are sometimes used for free cooling purposes, some costs of cooling towers were updated.

Information Sources

[1] Watt, Dr. John R., *Evaporative Air Conditioning Handbook*, Chapman and Hall, 1986.

[2] Thuman, Albert, *Optimizing HVAC Systems*, Fairmont Press, 1988.

8 Heat Pump

Heat pumps are a combination of cooling and heating equipment. Through the use of a special valve, the flow of refrigerant can be directed so either heating or cooling can be provided. Heat pumps can be broadly categorized by the medias in which the heat is transferred. Specifically, the four most common are:

- Air-to-Air
- Water-to-Air
- Air-to-Water
- Water-to-Water.

The last two can also be classified according to the way in which the water side heat transfer is handled. The water can be "ground source," meaning that the water is used and discharged, or it can be recirculated (called a closed loop heat pump). Another distinction is that of packaged and split units.

The current database does not distinguish between the various types of heat pumps. Instead, it groups them together and distinguishes only by cooling/heating capacity: 1, 5, 10, and 25 tons.

Maintenance consists of coil and air filter cleaning, descaling of units using water coils, compressor lubrication, and checks of the electrical controls and wiring. While maintenance costs for individual components of heat pumps was not available, overall service costs of 18,000 heat pumps was studied [1]. This study concluded that single package heat pumps installed before 1987 had higher maintenance costs. It also concluded that the costs for package and split units installed after that time were approximately equal.

Database Update

Component:	Heat Pumps xx Tons
System:	Heat/Cooling Generation
Subsystem:	Equipment
Tasks:	M/R, Replacement

The existing database had heat pumps of 1, 5, 10, and 25 ton units. These were not separated by the type of unit (air-to-air, water-to-air, air-to-water, water-to-water). While the initial cost and required maintenance was once higher for single package units, indicating a need for separate classifications, the costs are now approximately equal, negating this need. Because the use of ground-source heat pump systems has increased recently, an attempt was made to determine the installed cost of the water loop (once properly installed, this part of the system is virtually maintenance free). However, the types (vertical, horizontal, and well) and other variables (i.e., the number of heat pumps using the ground source) affect the cost to such a degree that estimating the cost requires a case-by-case analysis. This fact was documented by a recent study that reported the ground-source cost to be between $225/ton and $2448/ton [4], a 988 percent variation.

Information Sources

[1] *Heat Pump Repair Costs in Alabama*, EPRI EM-5328 Project 2417-1, July 1987.

[2] *Heat Pumps: Installation and Troubleshooting*, Sutphin, S. E., Fairmont Press, Inc., 1994.

[3] *Means Repair and Remodeling Cost Data*, 1994.

[4] Cane, Douglas, Blair Clemes, and Andrew Morrison, "Experiences With Commercial Ground-Source Heat Pumps," *ASHRAE Journal*, July 1996, pp 31-36.

[5] *Means Mechanical Costs Data*, 19th ed., R.S. Means Company, Inc., 1996.

9 Flue Gas Recirculation for Boilers

Background

Flue gas recirculation (FGR) is the technique used to reduce the pollutants produced from boilers by recirculating some of the flue gas back through the combustion chamber. Because the mechanical parts of FGR units are extremely simple, maintenance of this part of the boiler (when installed) is minimal. Basically, the units consist of ducting, a blower/fan, burner, dampers, burner, and controls. The major requirements are checking of the various components at regular intervals and lubrication. These checks and lubrication can be placed into four categories: daily, quarterly, semi-annual, and annual. Recommended frequency of these tasks was obtained and tabulated in the spreadsheet FGR.xls. Because the time required to perform the tasks tends to be independent of the boiler size, this data can be used for boilers in general.

Database Update

Component:	Flue Gas Recirculation
System:	Heating Generation
Subsystem:	Equipment
Tasks:	PM

Data in the FGR.xls spreadsheet were included in the database update.

Information Sources

Cleaver Brooks
Service Department
P.O. Box 421
7800 North 113th Street
Milwaukee, WI
(414) 359-0600
(414) 577-3021 Fax

Babcock & Wilcox
Robert J. Deptola
325 Ferguson Road
Homer City, PA 15748
(412) 479-3585
(412) 479-3911 Fax

10 Condensing Heat Exchangers

Condensing heat exchangers, sometimes referred to as CDX, are used to reclaim heat from the boiler flue gas. Because of the corrosive nature of flue gas, boilers are normally controlled so the temperature of the flue gas does not fall below that of the dewpoint (the point at which the vapors condense into liquid). Condensing heat exchangers are coated with a material such as teflon or polyphenylene sulfide [3] that can survive the corrosive nature of condensing flue gases. There are no moving parts to a heat exchanger, so very few maintenance items are required. Associated with this heat exchanger, however, are dampers and controls. The major concern in terms of maintenance is the clogging of these with soot.

Database Update

Component:	Condensing Heat Exchanger
System:	Heating Generation
Subsystem:	Equipment
Tasks:	PM and M/R, Replacement

Condensing heat exchangers are most commonly used in larger boiler units where economies of scale result in opportunities to save large sums of energy dollars. While they could be applied to smaller units, data did not indicate that it is a common practice. For this reason, only units 10 MBtu and larger were included in the database update.

Information Sources

[1] Case, Michael P., Sharon DeVelle, Richard Caron, and Thomas Pierce, *Performance of a Condensing Hat Exchanger in Recovering Waste Heat From a Natural Gas-Fired Boiler*, USACERL Technical Report E-90/09/ADA222456, May 1990.

[2] Snyder, Mathew E., Michael P. Case, Sharon Jones, and Richard Caron, *Performance of a Condensing Heat Exchanger System at Lake City Army*

Ammunition Plant, Independence, MO, Facilities Engineering Applications Program Technical Report E-92/09/ADA256356, June 1992.

[3] Gas Research Institute, "Evaluation of Alternative Materials for Condensing Heat Exchangers," GRI 90/0219.

11 Summary and Conclusions

Summary and Conclusions

Maintenance requirements for nine areas of HVAC equipment were evaluated. Most of the equipment involved a technology mature enough to collect meaningful data. Other technologies, such as evaporative cooling and free cooling, are still evolving and meaningful maintenance data were difficult to find and organize. The data collected were organized into spreadsheets, included as an appendix, and subsequently entered into a recently developed Windows version of the "Maintenance Task Data Base for Buildings: Heating, Ventilating, and Air-Conditioning (HVAC) Systems" [1]. Only major subtasks were updated in the database in order to remain as consistent as possible with the older database version. Maintenance requirements are of interest to many groups, and USACERL is not the only organization attempting to gather the data. ASHRAE Technical Committee 1.8 (Owning and Operating Costs) recently awarded a 1-yr contract to document HVAC maintenance costs that will be of great interest. This project has as one of its tasks to "summarize recurring and non-recurring maintenance costs for all systems and equipment analyzed including all factors which statistically affect results." The systems to be included range from air handling systems, water systems, heating and cooling generation equipment, to control systems. Specifically, items included in this report which are also included as part of this ASHRAE research effort include evaporative coolers, absorption chillers, engine-driven systems, and heat pumps. These data are expected to be available in July 1997. It is recommended that this effort be closely followed and that the results be included in the MRPM database.

Information Source

[1] Neely, Edgar S., Robert D. Neathammer, R. Stirn, and Robert P. Winkler, *Maintenance Task Data Base for Buildings: Heating, Ventilating, and Air Conditioning (HVAC) Systems,* USACERL Special Report P-91/21/ADA239954, May 1991.

Appendix: MRPM Database Spreadsheets

Table A1. CFC Changeout, CFC.XLS.

Component	Chiller xxxx Tons								
System	Cooling Generation								
Subsystem	Equipment								
Task(New)	CFC Changeout								
					SUBTASKS				Task Code
	Size (Tons)	Original Refrigerant	Replacement Refrigerant	RECLAIM	RETROFIT		NEW CHARGE		
				[Material] $	Material $	Labor Hours	Material $	Labor Hours	
A/C DX Packaged									
	5	HCFC-22		------Attrition------					
	20	HCFC-22		------Attrition------					
	50	HCFC-22		------Attrition------					
A/C Window									
	1	HCFC-22		------Attrition------					
	2	HCFC-22		------Attrition------					
A/C Pad Mounted									
	5	HCFC-22		------Attrition------					
	20	HCFC-22		------Attrition------					
Air Cooled Reciprocating									
	5	HCFC-22		------Attrition------					
	10	HCFC-22		------Attrition------					
	15	HCFC-22		------Attrition------					
	20	HCFC-22		------Attrition------					
	50	HCFC-22	R-407c	------Attrition------					
	100	CFC-12	R-409a	-640	2315	169	1276	18	0991434
	100	CFC-12	R-134a	-640	2315	169	666	18	0991435
Water Cooled Reciprocating									
	10	HCFC-22	------Attrition------						
	20	HCFC-22	------Attrition------						
	50	HCFC-22	------Attrition------						
	100	CFC-12	R-409a	-640	2315	169	1276	18	0991534
	200	CFC-11	R-123	-1280	2812	206	1800	35	0991554
	200	CFC-500	R-134a	-1280	2812	206	1,399	35	0991555
Hermetic Centrifugal									
	100	CFC-12	R-409a	-640	1276	287	1276	18	0991614
	300	CFC-11	R-123	-1920	5952	435	2700	53	0991624
	300	CFC-500	R-134a	-1920	5952	435	2,098	53	0991625
	900	CFC-11	R-123	-5760	8903	651	8100	158	0991634
	900	CFC-500	R-134a	-5760	8903	651	6,294	158	0991635
Hermetic Double Bun									
	100	CFC-12	R-409a	-640	4689	343	1148.4	18	0991813
	300	CFC-11	R-123	-1920	6575	481	2700	53	0991824
	300	CFC-500	R-134a	-1920	6575	481	2,098	53	0991825
	900	CFC-11	R-123	-5760	8903	651	8100	158	0991834
	900	CFC-500	R-134a	-5760	8903	651	6,294	158	0991835
Open Centrifugal									
	300	CFC-11	R-123	-1920	6575	481	2700	53	0991714
	300	CFC-500	R-134a	-1920	6575	481	2,098	53	0991715
	900	CFC-11	R-123	-5760	8903	651	8100	158	0991724
	900	CFC-500	R-134a	-5760	8903	651	6,294	158	0991725

Table A1. CFC Changeout, CFC.XLS (Cont'd).

	Replacement Refrigerant Costs								
Original Refrigerant	Replacement Refrigerants	Cost [$/#]	Reclaim Value [$/#]	Note					
R-22	R-407c	7.75	1.5	#1					
	R-410a								
	R-410b								
R-502	R-408a	4.6							
R-12	R-409a	6.38	3.2						
	R-134a	3.33							
	FR-12	12							
	R-401a			small, low temp equipment					
	R-401b								
	R-401c								
	R-406a								
	R-411a								
	R-411b								
R-11	R-123	4.5	3.2						
R-500	R-134a	3.33	3.2						
ASHRAE Feb '92 article estimated conversion of 500 ton R-11 to R-123 at $75,000									
	or $250/ton								
BOMA estimates $200/ton for R-11 to R-123 retrofit costs									
University of Maryland costs for R-11 to R-123:				$65/Ton Chiller Retrofit					
				$500/Ton Engineering design and Installation					
				$10/Ton Refrigerant compatability modifications					
				$5,000 for a refrigerant monitor					
Note 1	Can't be used for centrifugal chillers or others using a flooded evaporator, but chillers of this size don't typically use R-22								

Table A2. Gas Engine Driven Chillers, GEDCHIL.XLS.

Component	**GED Chiller xxxx Tons**										
System	**Cooling Generation**										
Subsystem	**Equipment**										
Task:			M/R			PM				Replace Gas Engine	
Subtask:			Overhaul - Top End	Overhaul - Entire Engine	Task Code	Recurring	Seasonal Shutdown/ Startup	Annual	Task Code		Task Code
Air Cooled Reciprocating											
	100	Material	$1,400	$4,000	0991436	$60	$375	$575	0991437	66505	0991438
		Labor (Hr)	35	65		10	12	20		847	
Water Cooled Reciprocating											
	100	Material	$1,400	$4,000	0991535	$60	$375	$575	0991536	66505	0991537
		Labor (Hr)	35	65		10	12	20		847	
	200	Material	$2,800	$8,000	0991556	$60	$375	$575	0991557	84186	0991558
		Labor (Hr)	40	75		10	12	20		1082	
Hermetic Centrifugal											
	100	Material	$1,400	$4,000	0991614	$60	$375	$575	0991615	66505	0991616
		Labor (Hr)	35	65		10	12	20		847	
	300	Material	$4,200	$12,000	0991626	$60	$375	$575	0991627	173851	0991628
		Labor (Hr)	45	84		10	12	20		1288	
	900	Material	$12,600	$36,000	0991636	$60	$375	$575	0991637	508016	0991638
		Labor (Hr)	73	142		10	12	20		2937	
Hermetic Double Bun											
	100	Material	$1,400	$4,000	0991815	$60	$375	$575	0991816	66505	0991817
		Labor (Hr)	35	65		10	12	20		847	
	300	Material	$4,200	$12,000	0991826	$60	$375	$575	0991827	173851	0991828
		Labor (Hr)	45	84		10	12	20		1288	
	900	Material	$12,600	$36,000	0991836	$60	$375	$575	0991837	508016	0991838
		Labor (Hr)	73	142		10	12	20		2937	
Open Centrifugal											
	300	Material	$4,200	$12,000	0991716	$60	$375	$575	0991717	173851	0991718
		Labor (Hr)	45	84		10	12	20		1288	
	900	Material	$12,600	$36,000	0991726	$60	$375	$575	0991727	508016	0991728
		Labor (Hr)	73	142		10	12	20		2937	

Table A3. Direct-Fired Absorption Chillers, ABSORP.XLS.

Component	**Two Stage Direct Fired Absorption Chiller xxxx Tons**								
System	**Cooling Generation**								
Subsystem	**Equipment**								
Task		Maintenance/Year			Replacement				
	(Tons)	Labor	Labor	Task Number				Avg Freq	Task Number
		1994$	Hours		Materials	Labor	Labor		
					1994$	1994$	[Hours]		
	100	2300	56	0991A11	77565	25855	629	22 years	0991A12
	150	3450	84	0991A21	112984	37661	916	22 years	0991A22
	240	5520	134	0991A31	171086	57029	1388	22 years	0991A32
	300	6900	168	0991A41	205785	68595	1669	22 years	0991A42
	360	8280	201	0991A51	237254	79085	1924	22 years	0991A52
	500	11500	280	0991A61	298125	99375	2418	22 years	0991A62
	600	13800	336	0991A71	330840	110280	2683	22 years	0991A72
	900	20700	504	0991A81	375165	125055	3043	22 years	0991A82

Table A4. Desiccant Systems, DESICANT.XLS.

Component:	Desiccant Chiller xxxx SCFM (Retrofit and Stand Alone)							
System:	Cooling Generation							
Subsystem:	Equipment							
	Task Description:	**PM Labor Hours/Year [Desiccant Unit]**				**Replacement**		
	Subtask:	Recurring	Seasonal Shutdown	Annual	Task Number	Labor[hours]	Material Costs($)	Task Number
Unit Capacity [SCFM]								
	De-Humidification Only (Retrofit)							
2500		2.8	4	0.9	0991G10	122	$20,000	0991G11
5000		2.8	4	0.9	0991G20	201	$33,000	0991G21
10000		2.8	4	0.9	0991G30	225	$37,000	0991G31
	Complete Dessicant/AHU							
20000		2.8	4	0.9	0991G40	353	$58,000	0991G41
28000		2.8	4	0.9	0991G50	401	$66,000	0991G51
38000		2.8	4	0.9	0991G60	441	$72,500	0991G61

Table A5. Evaporative Cooling, EVAP.XLS.

Component	Evaporative Cooling - Type(Precool only, Cool, Direct/Indirect) - Size (SCFM)					
System	Cooling Generation					
Subsystem	Equipment - Direct Evaporative Cooling					
	Task Description:	**PM Labor Hours/Year**		**Replacement**		Lifetime = 20 years
			Task Number	Labor[hour	Material Costs($)	Task Number
Unit Type	Unit Capacity					
Precool Only - Indirect	2000 SCFM	4	0991H10	44	$5,452	0991H11
Precool Only - Indirect	5000 SCFM	4	0991H20	68	$8,508	0991H21
Precool Only - Indirect	15000 SCFM	12	0991H30	181	$22,565	0991H31
Cool - Direct W/Heating	4 Tons	3	0991H40	71	$8,862	0991H41
Cool - Indirect and Direct W/Heating	4 Tons	4	0991H50	65	$8,038	0991H51
Cool - Indirect and Direct W/Heating	20 Tons	12	0991H60	181	$22,544	0991H61

Table A6. Cooling Tower Update, FREECOOL.XLS.

Component	Cooling Tower xxxx Tons		
System	Cooling Generation		
Subsystem	Equipment		
Capacity	Type	Replacement Cost	
[Tons]		Material	
		[1996 $]	
			Task Code
50	Draw Thru, belt drive, single flow Galvanized Steel	3575	0991C13
100	Draw Thru, belt drive, single flow Galvanized Steel	6200	0991C23
300	Induced air, gear driven, double flow Galvanized Steel	16950	0991C33
900	Induced air, gear driven, double flow Galvanized Steel	36000	0991C43

Table A7. Heat Pumps. HEATP.XLS.

Component:	Heat Pump xx Tons									
System:	Heat/Cool Generation									
Subsystem:	Equipment									
Task Description:		Replace		M/R						
				Material						
Unit Size [Tons]		Material	Task Code	Sup Fan Motor	Cond Fan Mtr	Refrigeran	Heater	Humidifier	Compressor	Task Code
1		$1,700	09A1E43	114	114	$16	170	N/A	264	09A1E41
5		$3,317	09A1E13	206	114	$78	332	2375	580	09A1E11
10		$8,250	09A1E23	220	114	$155	825	2375	1550	09A1E21
25		$16,725	09A1E33	249	114	$388	1673	2375	8438	09A1E31

Table A8. Flue Gas Recirculation, FGR.XLS.

Component:	Boiler Flue Gas Recirculation Maintenance				
System:	Heating Generation				
Subsystem:	Equipment				
Task Description:		**Flue Gas Recirculation PM**			
		Labor [Hours]			
		Recurring	Seasonal Shutdown	Annual	Task Code
		2	2.6	2.1	0981P00

Table A9. Condensing Heat Exchangers, CDX.XLS.

Component	**Condensing Heat Exchanger**					
System	**Heating Generation**					
Subsystem	**Equipment**					
Task Description		**PM/MR - Condensing Heat Exchanger**		**Replacement**		**Life equal to boiler**
Boiler Type	Size	Labor Hours/Yr	Task Code	Material	Labor	Task Code
	MBTU					
Gas	10	31.3	0981138	33795	11265	0981139
Coal	40	31.3	0981216	117720	39240	0981217
Coal	100	31.3	0981226	207000	69000	0981227
Oil	10	31.3	0981337	33795	11265	0981338
Gas/Oil	20	31.3	0981426	64680	21560	0981427

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